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PERFORMANCE OF SMALL REACTORS AT UNIVERSITIES FOR TEACHING, RESEARCH, TRAINING AND SERVICE (TRTS): THIRTY FIVE YEARS' EXPERIENCE WITH THE DALHOUSIE UNIVERSITY SLOWPOKE-2 REACTOR

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ABSTRACT – The Dalhousie University SLOWPOKE-2 Reactor (DUSR) facility, operated during 1976-2011, was the only research reactor in Atlantic Canada as well as the only one associated with a chemistry department in a Canadian university. The most outstanding features of the facility included: a rapid (100 ms) cyclic pneumatic sample transfer system, a permanently installed Cd-site, and a Compton-suppression gamma-ray spectrometer. The usage encompassed fundamental as well as applied studies in various fields using neutron activation analysis (NAA). The facility was used for training undergraduate/graduate students, postdoctoral fellows, technicians, and visiting scientists, and for cooperative projects with other universities, research organizations and industries.

The Trace Analysis Research Centre (TARC), an analytical chemistry centre of excellence and the first of its kind in Canada, was established in 1971 at the Department of Chemistry of Dalhousie University through a Negotiated Development Grant from the then National Research Council of Canada (NRCC). A provision was made to appoint a radiochemist at TARC in 1974. The DUSR was purchased from the Atomic Energy of Canada Limited - Commercial Products (AECL-CP) with the financial assistance from NRCC ($165,000) in the form of a Major Equipment Grant. Dalhousie University spent about $100,000 for the installation of the DUSR facility in 1976 June at the Life Sciences Centre of its Studley campus.

The DUSR was one of the four SLOWPOKE-2 research reactor facilities with different mandates and supported by NSERC. The other three SLOWPOKE-2 facilities were located at Ecole Polytechnique in Montreal, University of Toronto in Toronto, and University of Alberta in Edmonton. Our University decided on the following mandates of teaching, research, training and service (TRTS) for the DUSR facility: (i) to promote and carry out innovative, fundamental and applied studies in nuclear analytical chemistry, NAA in particular; (ii) to provide technical support to scientists at Dalhousie and other universities and research organizations in the Atlantic region; (iii) to train highly qualified personnel (namely graduate students, postdoctoral fellows, technicians, research associates, and visiting scientists/professors) in nuclear analytical chemistry; (iv) to teach undergraduate students; (v) to get involved in cooperative projects with industries and universities, particularly in Atlantic Canada, by developing NAA methods for their research projects; and (vi) to provide some analytical services to local, regional, national and international academic, non-academic research, and commercial organizations.

SLOWPOKE-2 is a relatively small research reactor. Although it is capable of producing daily maximum neutron flux of 1×10^{12} cm^{-2} s^{-1} for about 4 h at 16 kW operating power, the DUSR was generally operated at 8 or 4 kW for a neutron flux of either 5 or 2.5 $\times 10^{11}$ cm^{-2} s^{-1} to meet the needs of users for longer daily operating hours. This flux was one to two orders of magnitude lower than most other research reactors in the world but that did not adversely affect innovative usage of DUSR as described below. The samples were irradiated during both day and night times: 09:00-17:00 h in presence of operators and 17:00-09:00 h under remote surveillance during the weekdays. The DUSR was operated throughout the year excluding holidays.

At DUSR, we were mainly involved with the development of innovative nuclear analytical methods for both fundamental as well as applied studies and able to exploit many beneficial features of SLOWPOKE-2 reactors. Although NAA was a well-established analytical technique, much of the activation analysis being done in Canada and elsewhere for that matter was limited to methods using fairly long-lived nuclides. Our approach at DUSR was to utilize the highly homogeneous, stable and reproducible flux to develop NAA methods based on short-lived nuclides. A rapid cyclic pneumatic system with transfer time of about 100 ms from reactor core to a detector, only one of a kind in North America, was designed by us and installed at DUSR.

The SLOWPOKE-2 reactor with its fairly high epithermal neutron flux was advantageously used in our laboratory for measuring several trace elements in complex matrices such as geological materials and glass containing large amounts of Na, Cl, Al, Mn, V *etc*. Extensive studies were carried out at DUSR on both boron and cadmium shields. The first cadmium shielded pneumatic site in a SLOWPOKE reactor was installed at the DUSR facility. The epi-cadmium neutron flux was characterized in detail, and theoretical and practical advantage factors were determined for many elements of interest. Vials of high purity boron were also designed and fabricated in our laboratory for studying short-lived epithermal neutron activation products.

The relatively low water moderator temperature (maximum of 48^{o}C) at DUSR offered the great advantage of direct irradiation of liquid and wet samples in normal polyethylene vials without any detectable loss of elements of interest in materials such as rain and ground water, food, proteins, *etc*. Pre-irradiation preconcentration and/or post-irradiation radiochemical separations using novel chemical compounds were employed in our laboratory. Concentrations of many trace elements in water and similar samples cannot be measured directly by most instrumental techniques due to several reasons. Very low levels of the elements of interest, insufficient sensitivity of many instrumental techniques, interference from major elements in the matrix, and the need to use large volumes of water as representative samples have made preconcentration procedures indispensable. Methods involving coprecipitation of trace elements with organic chelating agents were developed in our laboratory because they could be used in conjunction with NAA due to the relatively high purity of the organic reagents in terms of inorganic contaminants, to their general lack of affinity for alkali and alkaline earth metal ions, and to their low induced radioactivity.

The DUSR facility housed inactive and radiochemical laboratories fitted with fume hoods and specialized glove boxes, sample handling room, counting rooms, *etc*. Other facilities included Ge(Li), hyperpure Ge, low-energy photon, well-type Ge and NaI(Tl), and anti-coincidence gamma-ray detectors, alpha-ray detectors, and computerized spectrometers.

The AECL-CP, supplier of the SLOWPOKE reactors, predicted a life time of approximately 10 years for the reactor fuel under normal operating power of 20 kW. In 1986, after successful operation for 10 years, the DUSR fuel needed to be refurbished. The DUSR facility was used so extensively that it was the first of the two SLOWPOKEs needed to be fitted with an additional large beryllium shim tray on the top of the existing beryllium reflector to extend the fuel core life. It was done in 1986 at Dalhousie University and in 1987 at the University of Toronto.

The number of senior users varied between 22 and 32 with an average of 25. The users came from various organizations including (i) many departments within Dalhousie University (*e.g.* Chemistry, Earth Sciences, Physics, Biology, Biochemistry, Epidemiology, Oceanography, Chemical Engineering, Civil Engineering, Food Sciences technology), universities in Atlantic Canada (*e.g.* St. Mary's Univ, Univ de Moncton, Univ of New Brunswick, Memorial Univ of Newfoundland), other Canadian universities (*e.g.* Univ of Alberta, Univ of Toronto), universities from other countries (*e.g.*Massey Univ in NZ, Academia Sinica in Shanghai, Univ of West Indies in Jamaica, Ahmadu Belo University in Nigeria); (ii) hospitals (*e.g.* Izaak Walton Killam Hospital and Cancer Treatment and Research Foundation of NS in Halifax, Hopital Sainte-Justine in Montreal); (iii) Canadian Federal and Provincial government research and service laboratories (*e.g.* Institute for Marine Biosciences, NRC, Halifax; Measurement Science Lab of NRC in Ottawa, Health Canada labs in Ottawa and Dartmouth, Fisheries and Oceans Canada in St. John's and Halifax, Atomic Energy of Canada Limited Research labs at Chalk River and Whiteshell); (iv) international (*e.g.* Office of Atom for Peace in Thailand, Ghana Atomic Energy Commission in Ghana, Department of Atomic Energy in Myanmar, National Institutes of Health in USA, International Atomic Energy Agency in Austria); and (v) industries (*e.g.* Acadian Seaplants in Halifax, Imperial Oil in Dartmouth, SepraChem in Windsor, Seagull Pewters and Silversmiths in Pugwash, NS: Food Technology Centre in Charlottetown, Alcan International in Sudbury, Johnson Matthey Electronics in Vancouver, Eastman Kodak in Rochester, NY, USA).

The scientists trained at the DUSR facility are making valuable contributions in many areas as (i) academics at the Memorial Univ of Newfoundland, Univ of Ottawa, NS Community College in Dartmouth, Institute of Nuclear Science and Technology in Cuba, *etc*.; (ii) academics/administrators at Ghana Atomic Energy Commission, Postgraduate School of Nuclear and Allied Sciences, Univ of Ghana, Bhabha Atomic Research Centre in India, *etc*; (iii) at government and national labs such as Health Canada, Chalk River Laboratories, State of Maryland Analytical Laboratory, USA *etc*; (iv) at industries such as BioVectra in Charlottetown, Petro-Canada Lubricants Inc. in Mississauga, GlaxoSmithKline, Inc. in NC, Biogen-Idec Inc in Durham, NC; Founder & Owner, BBF Consultants in Hamilton, ON. At DUSR facility I trained several foreign students and visiting scientists sponsored by IAEA, CIDA, Commonwealth Foundation, *etc*; almost all of them went back to their home countries. Many of them came from laboratories (often countries) where no nuclear analytical chemistry was either taught or practiced. These graduates started research and training as well as degree programs in analytical, nuclear analytical, environmental, and radiochemistry upon return to their native countries. All the things described above were possible to do because of the availability of a small, inherently safe research reactor called SLOWPOKE-2 operated at Dalhousie University in downtown Halifax for 35 years without any problem. It was decommissioned in 2011 February. Peoples Republic of China built Miniature Neutron Source Reactor (MNSR) which is very similar to SLOWPOKE-2 and sold several of them within and outside China.